FRICKE AND ALANINE DOSIMETERS

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Chemical dosimeters

In a chemical dosimeter the absorbed dose is determined from some quantitative change in an appropriate material and any well-characterized chemical reaction may serve as the basis for the dosimeter.

Fricke – the basics

- The chemical species of interest is the production of Ferric ions (Fe^{3+}) from Ferrous ions (Fe^{2+})
- The Ferrous ions are in solution
- What is irradiated is therefore mainly water
- Ionizing radiation interacting with water produces a range of ions, radicals and molecules:

$H\cdot$ $OH\cdot$ H_2 H_2O_2 H^+ OH^- e^-_{aq}

Lots of products, therefore a lot of reactions

$$H + O_2 \rightarrow HO_2$$

$$Fe^{2+} + HO_2 \rightarrow Fe^{3+} + HO_2^-$$

$$HO_2^- + H^+ \rightarrow H_2O_2$$

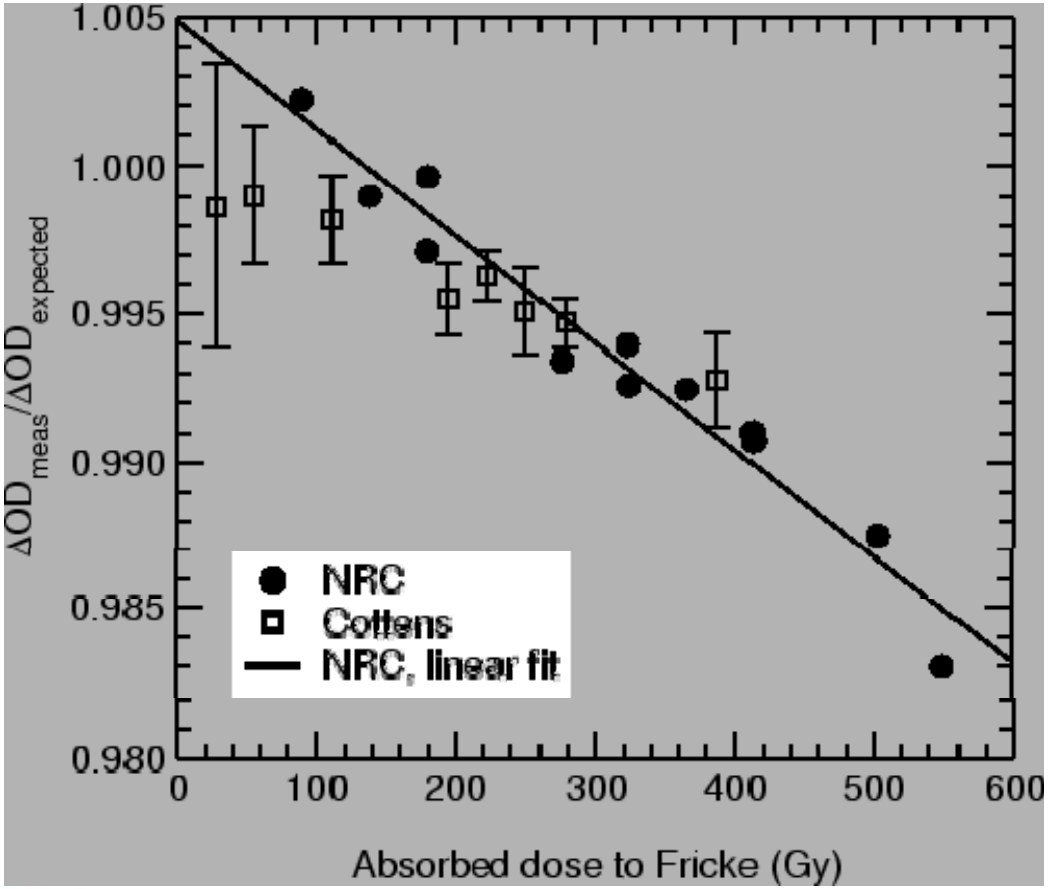
$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH + OH^-$$

$$Fe^{2+} + OH \rightarrow Fe^{3+} + OH^-$$

Note that O_2 is needed.

Dose range

Oxygen is the limiting factor, rather than the concentration of Fe^{2+}
The maximum absorbed dose that can be measured is about 400 Gy.



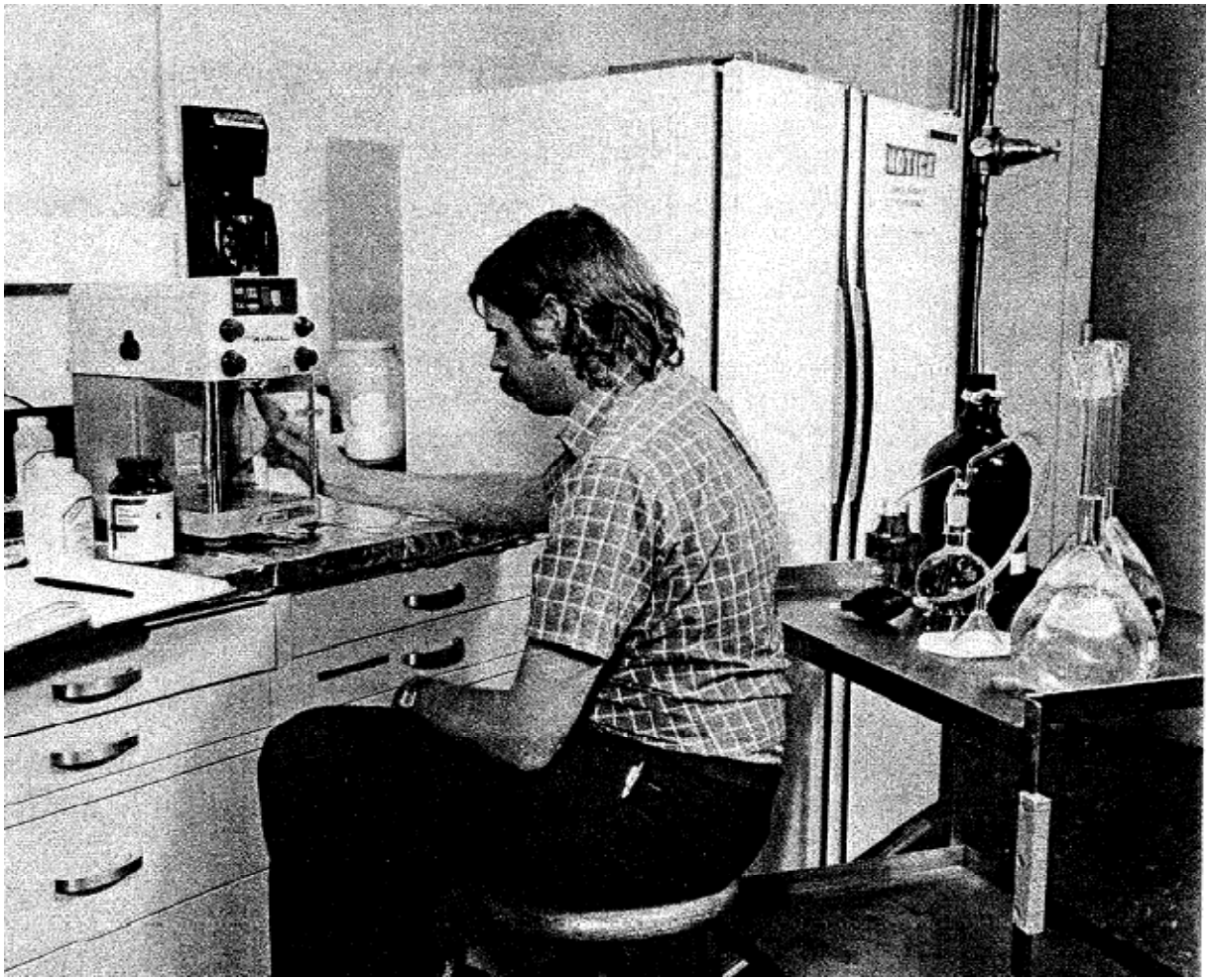
Chemistry - preparation

❖ The Fricke solution consists of 1mM ferrous ammonium sulfate and 1mM sodium chloride in 0.4 M sulfuric acid.

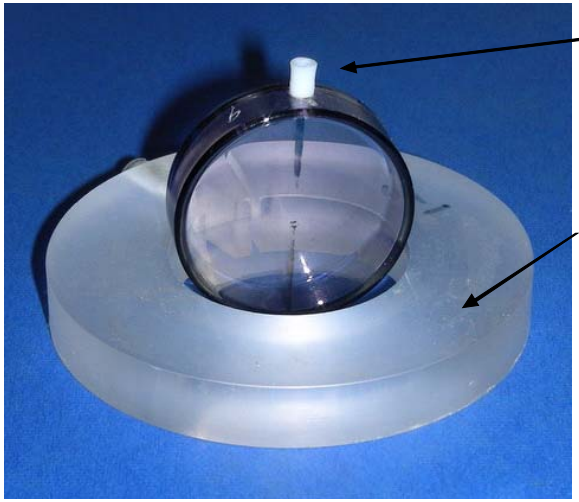
❖ Contaminants can significantly affect performance therefore care must be taken to clean all glassware carefully and to use high purity chemicals.

❖ Sodium chloride is added to reduce or eliminate any sensitivity to organic impurities.

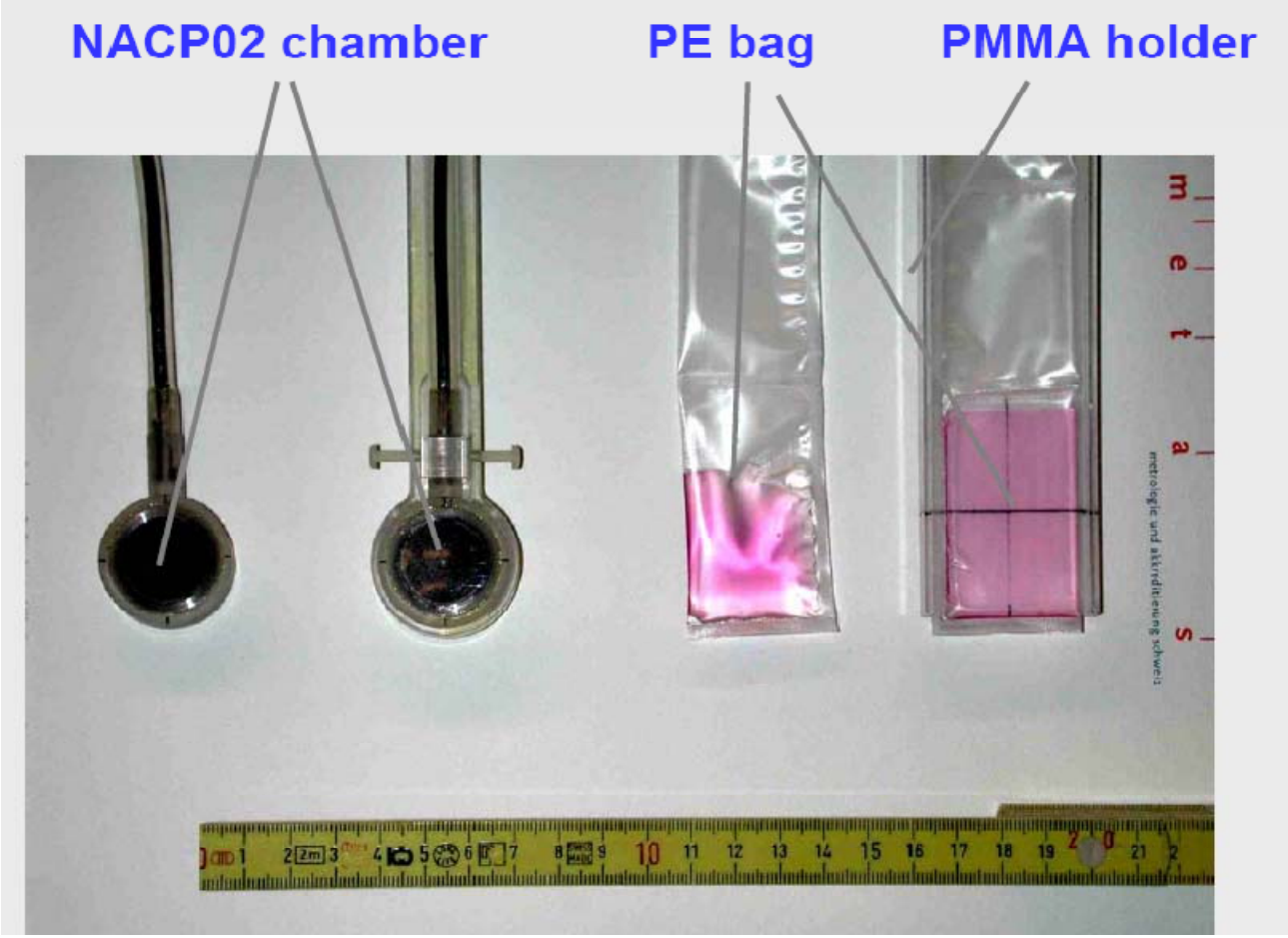
Chemistry - preparation



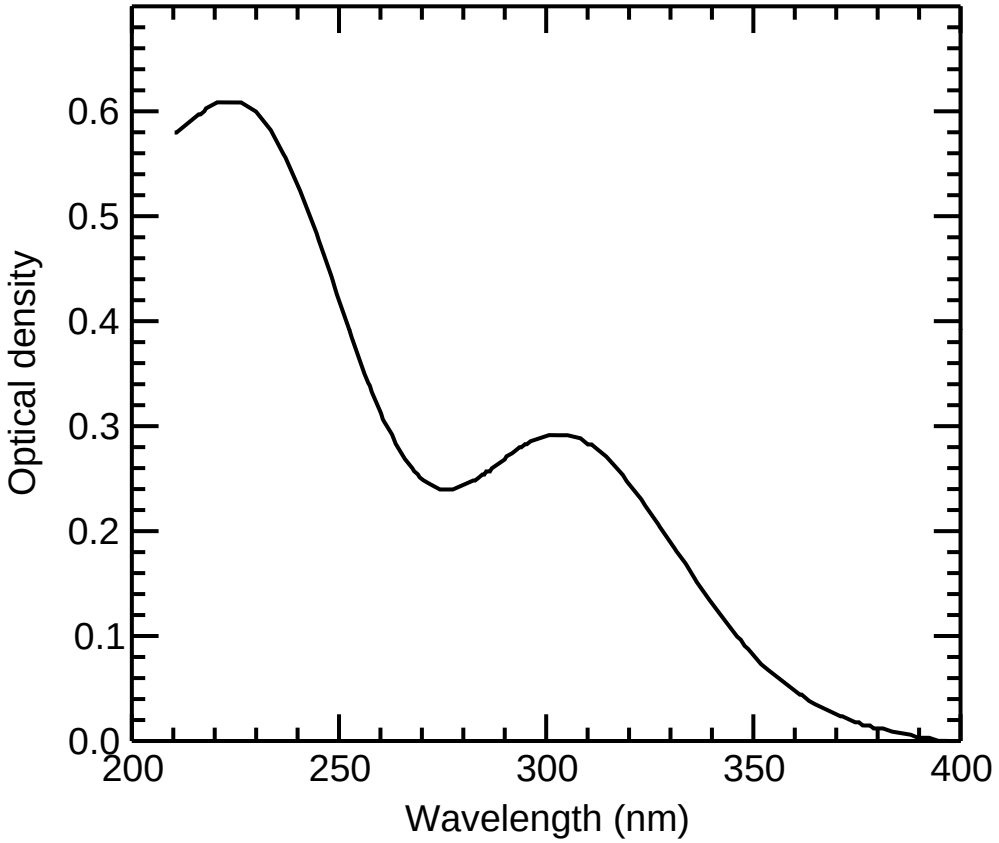
Containment - standard



Containment - specialized



Readout



Peaks at 224 nm and 303 nm

Commercial spectrophotometers usually use both

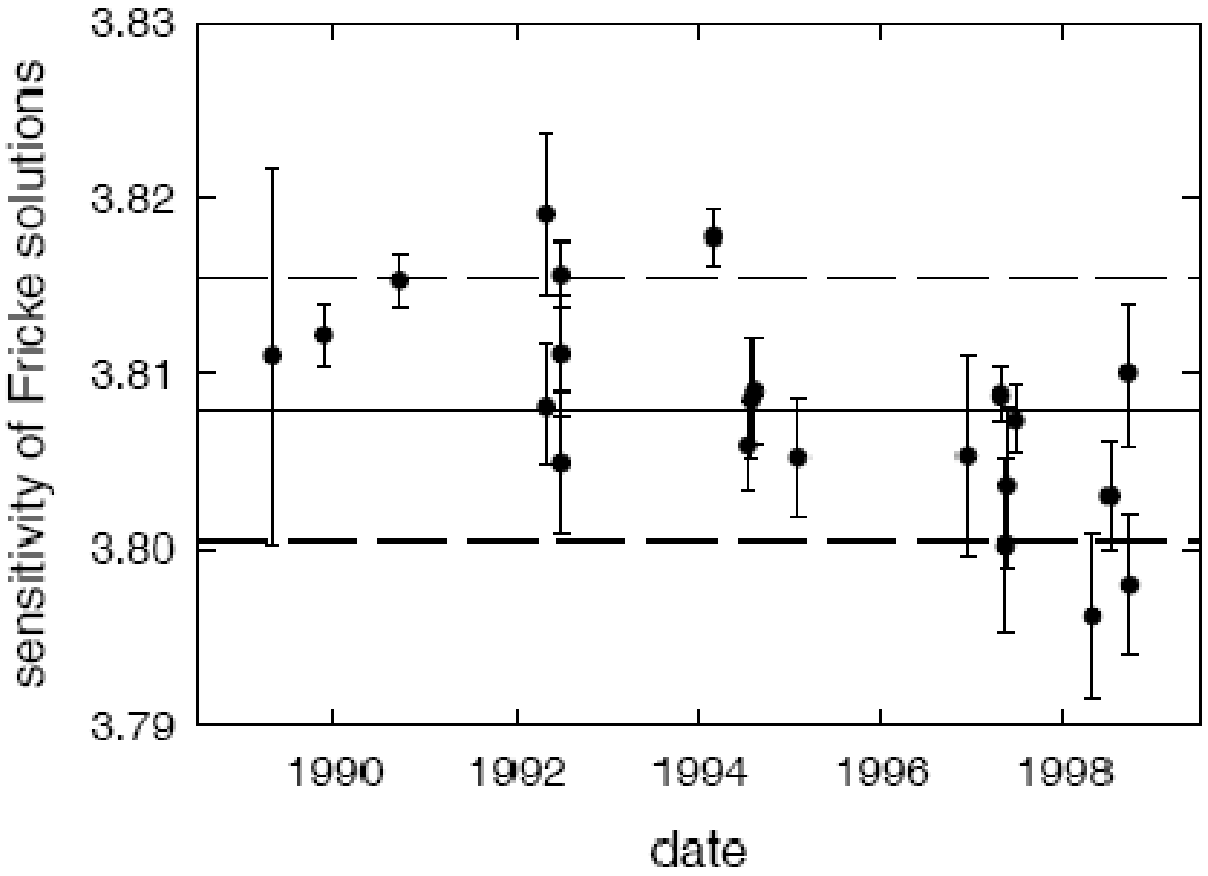
Readout

$$OD = \log_{10}(I_0 / I) = c \cdot L \cdot \varepsilon$$

- The yield of the Fe^{3+} ion depends on the temperature of the solution during irradiation (0.12% per degree C)
- The molar extinction coefficient depends on the temperature of the solution during readout

$$D_F = \frac{\Delta OD}{\varepsilon \cdot G(Fe^{3+}) \cdot \rho \cdot L}$$

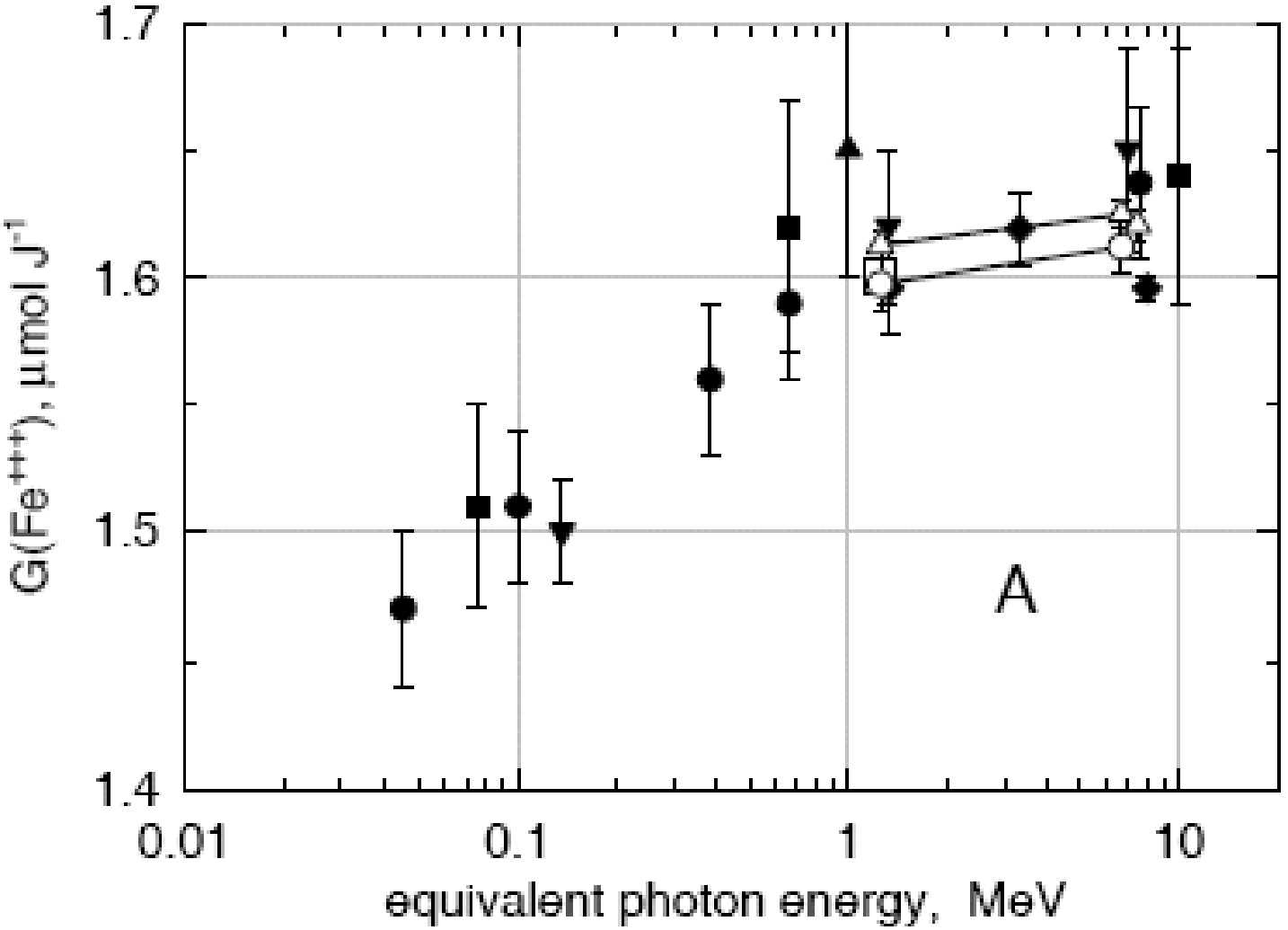
Reproducibility



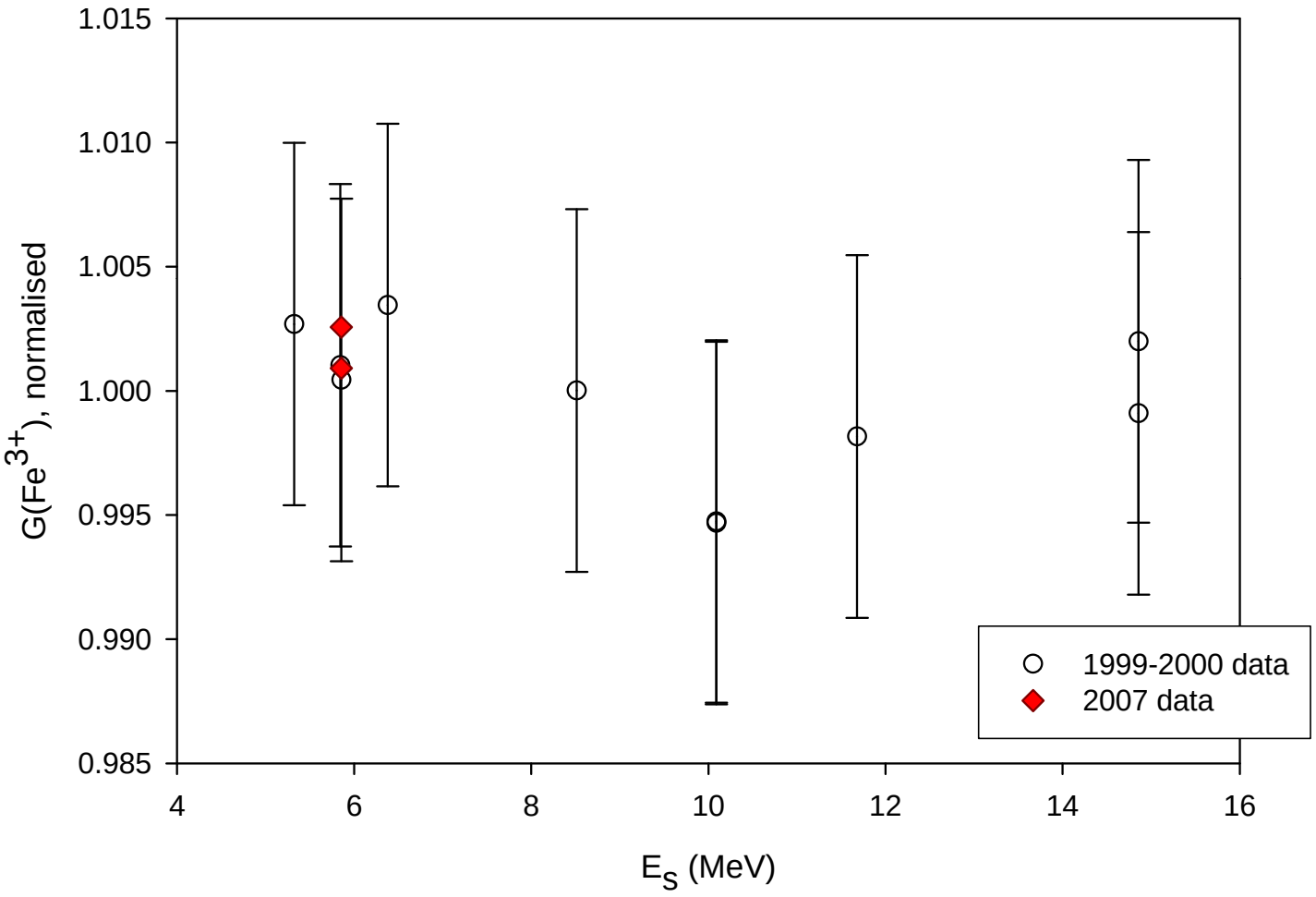
Precision is typically better than 0.15 %

Stability of the dosimeter response is only slightly worse.

Energy dependence – photon beams



Energy dependence – electron beams



Measurement of dose

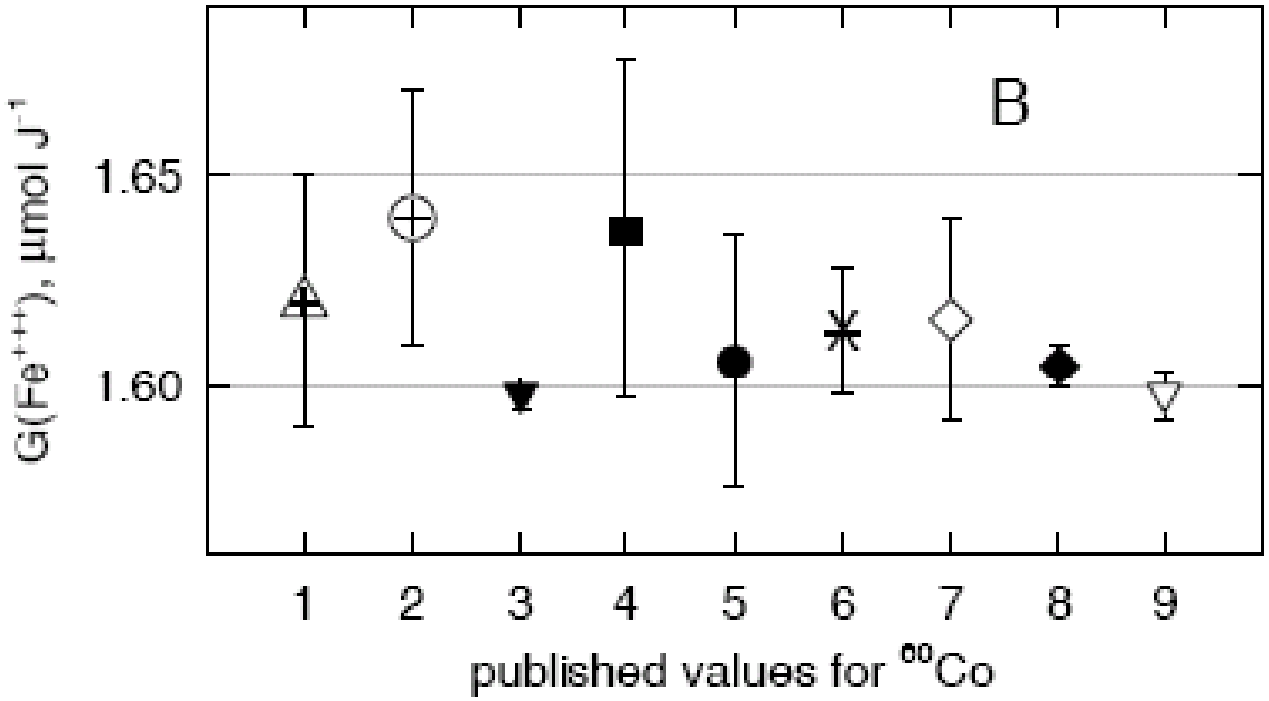
$$D_F = \frac{\Delta OD}{\varepsilon \cdot G(Fe^{3+}) \cdot \rho \cdot L}$$

$$D_w = D_F \; f_{w,F} \; P_{wall} \; k_{dd}$$

$$f(Q) = f_{w,F} \; P_{wall}$$

Is Fricke a primary or secondary dosimeter?

$$D_F = \frac{\Delta OD}{\varepsilon \cdot G(Fe^{3+}) \cdot \rho \cdot L}$$



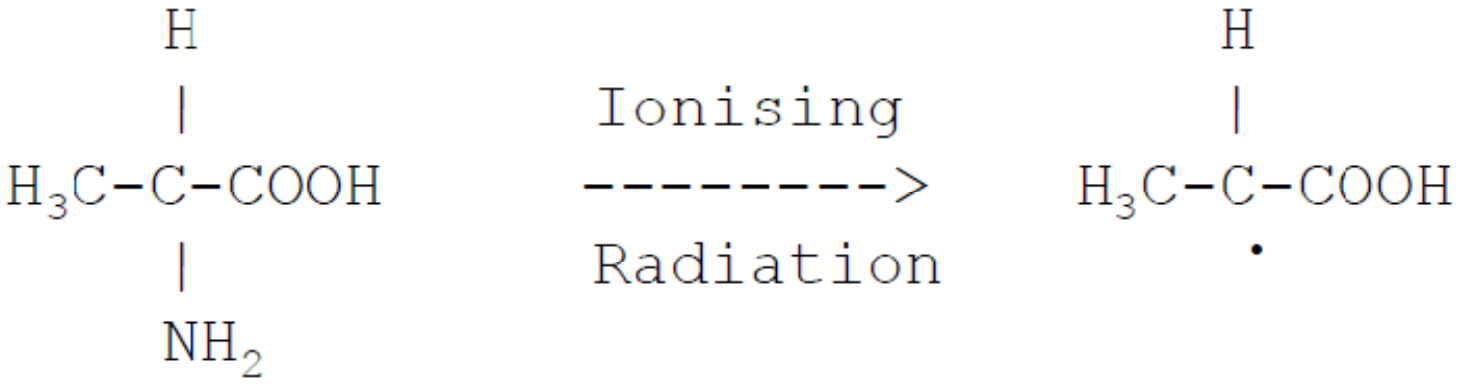
Applications today

Fricke is disappearing from even primary standards laboratories. Does it have a future?

- Low energy electron beam dosimetry
- Ir-192 dosimetry

Alanine – the basics

Irradiation of the amino acid alanine produces stable free radicals:



The concentration of the radicals is proportional to the absorbed dose and can be measured by Electron Paramagnetic Resonance (EPR) spectroscopy.

Alanine - development

Major players:

NIST

NPL

Latecomers:

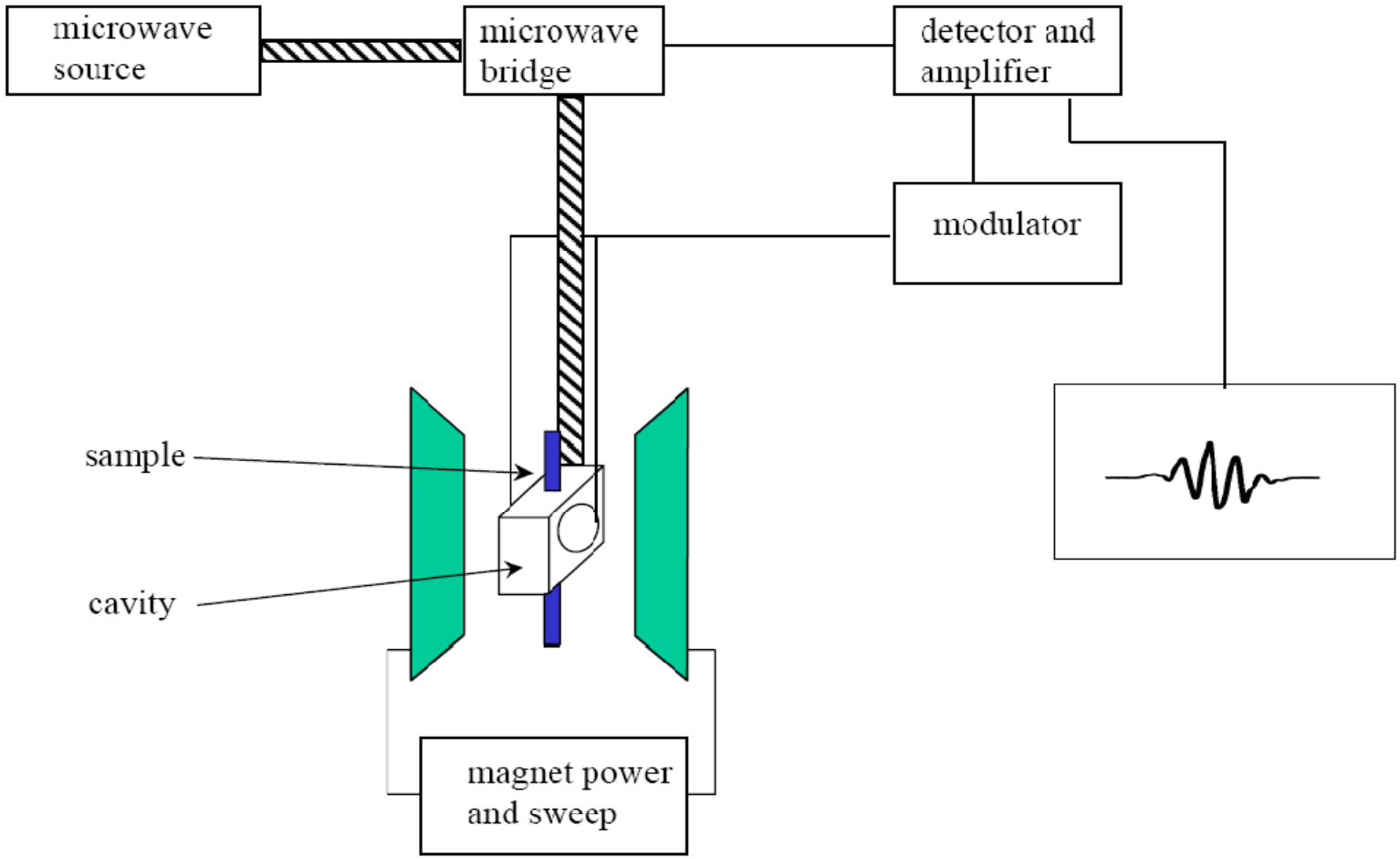
NRC

PTB

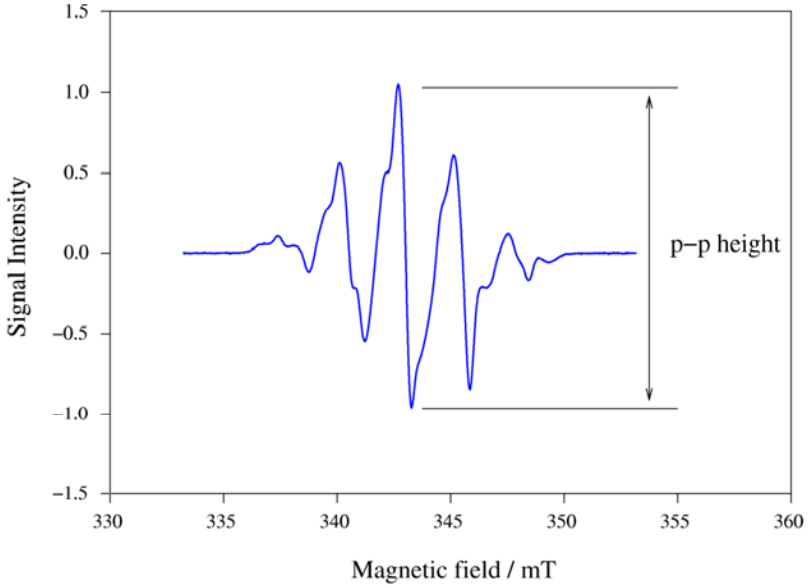
Alanine pellets

- 90% alanine, 10% paraffin wax (m.p. 98°C)
- 55 mg mass (nominal)
- 5 mm diameter, ~2.5 mm thick
- ~1.2 g cm^{-3} density

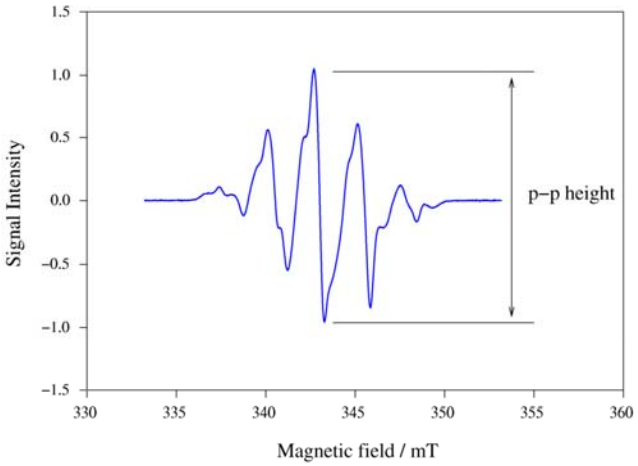
Alanine – readout

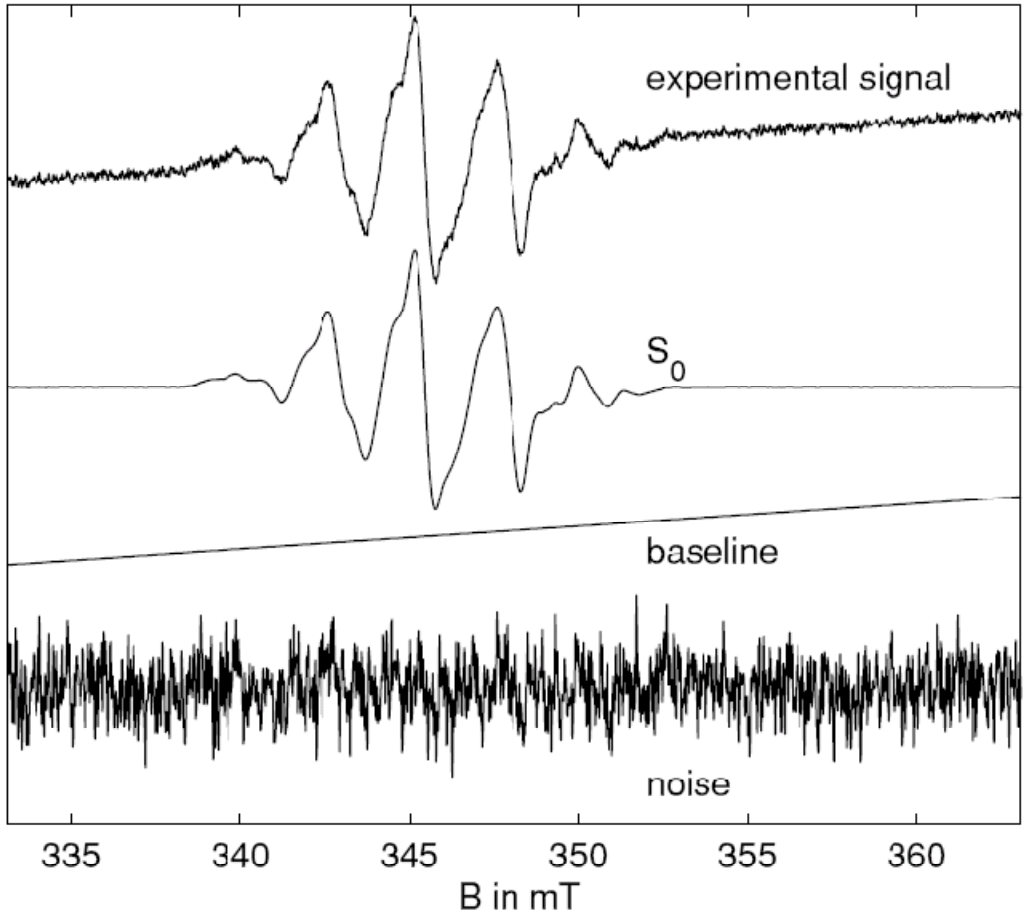


Alanine – readout

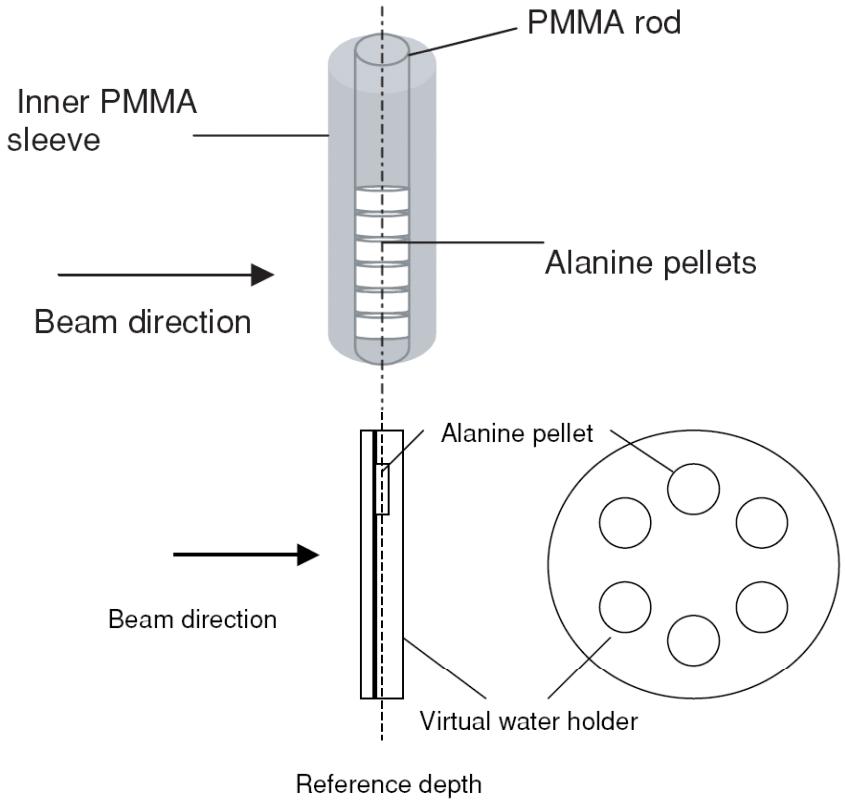


Signal Extraction

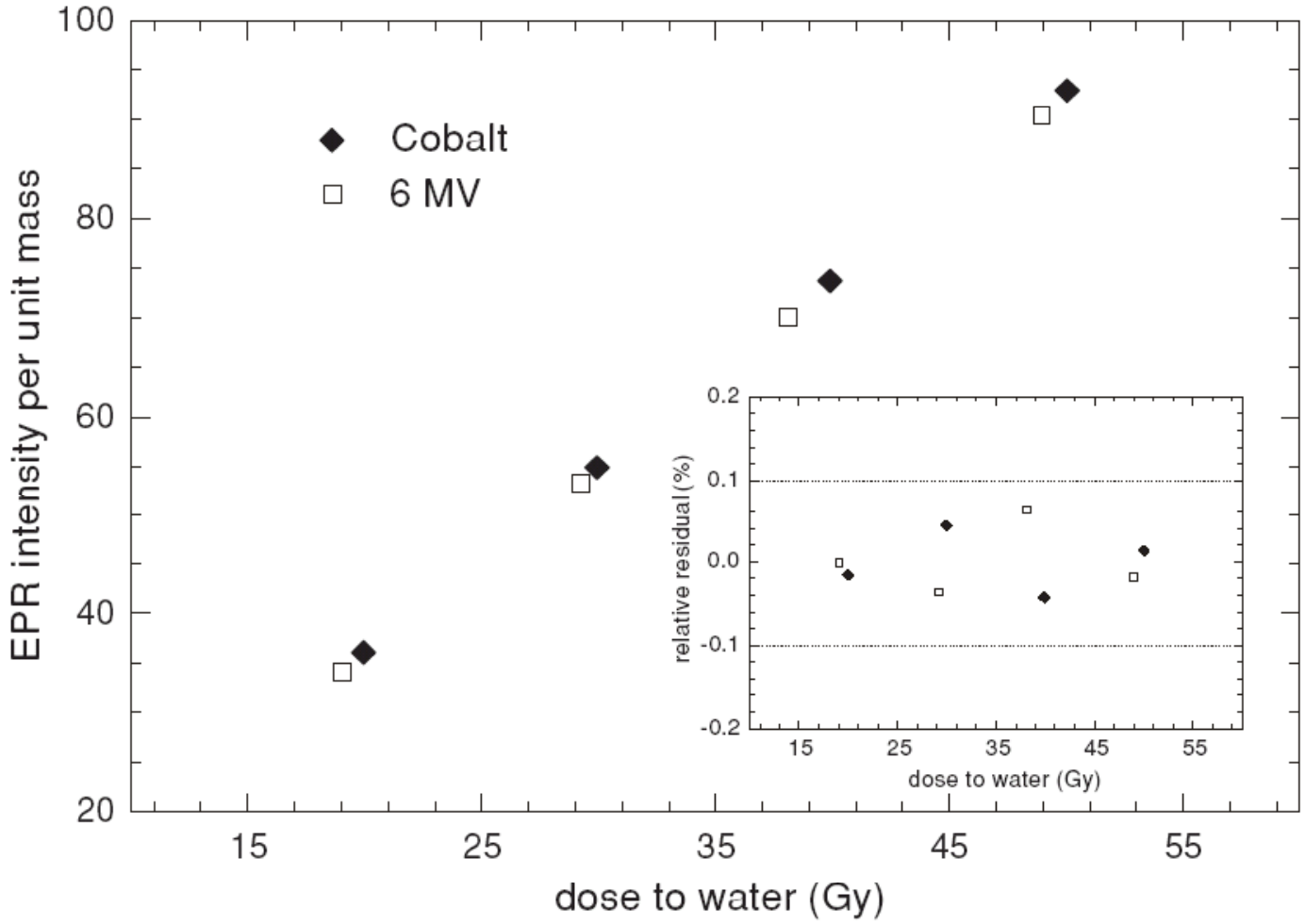




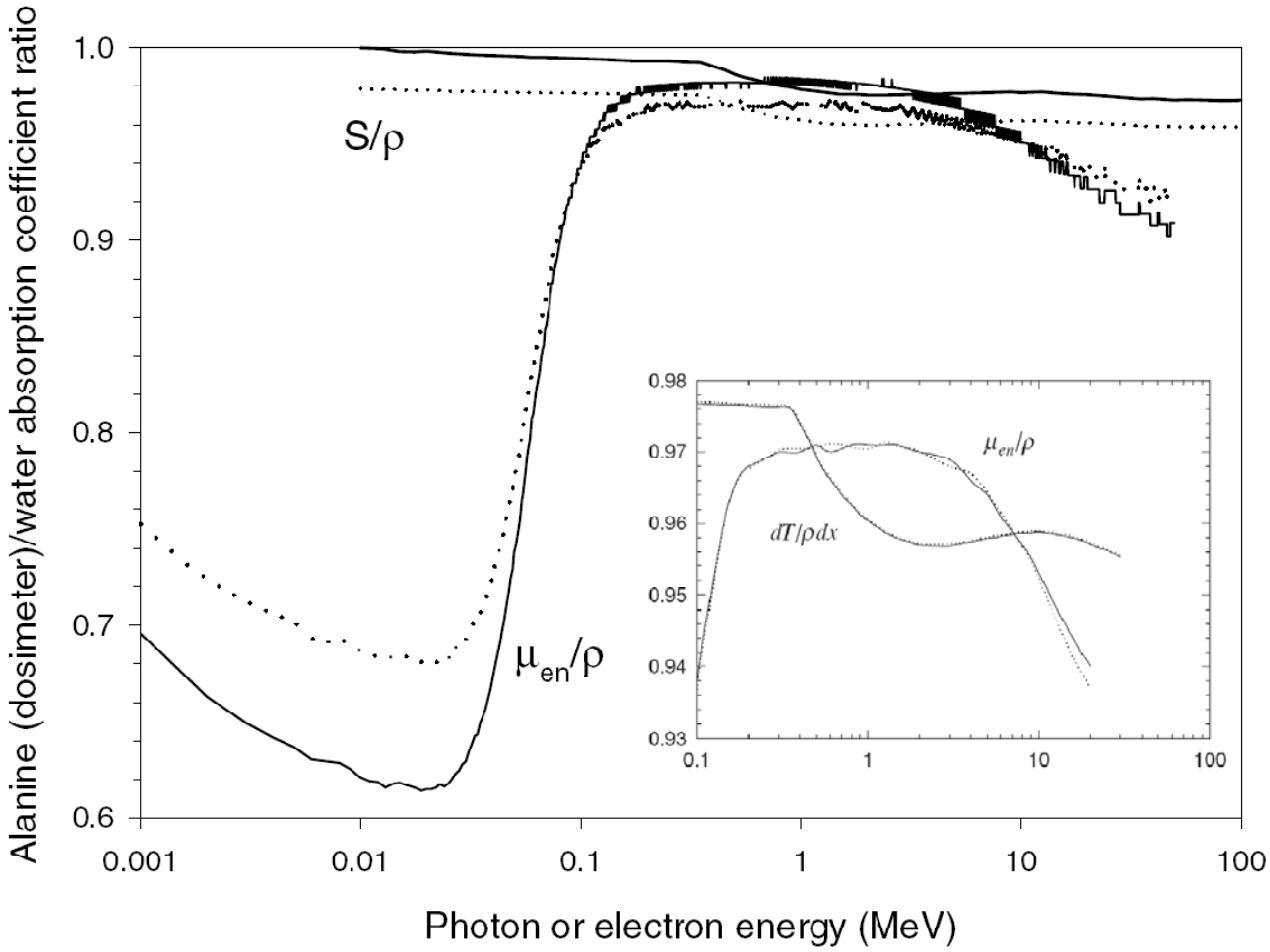
Holders


PMMA rod
Inner PMMA sleeve
Alanine pellets
Beam direction
Alanine pellet
Beam direction
Virtual water holder
Reference depth

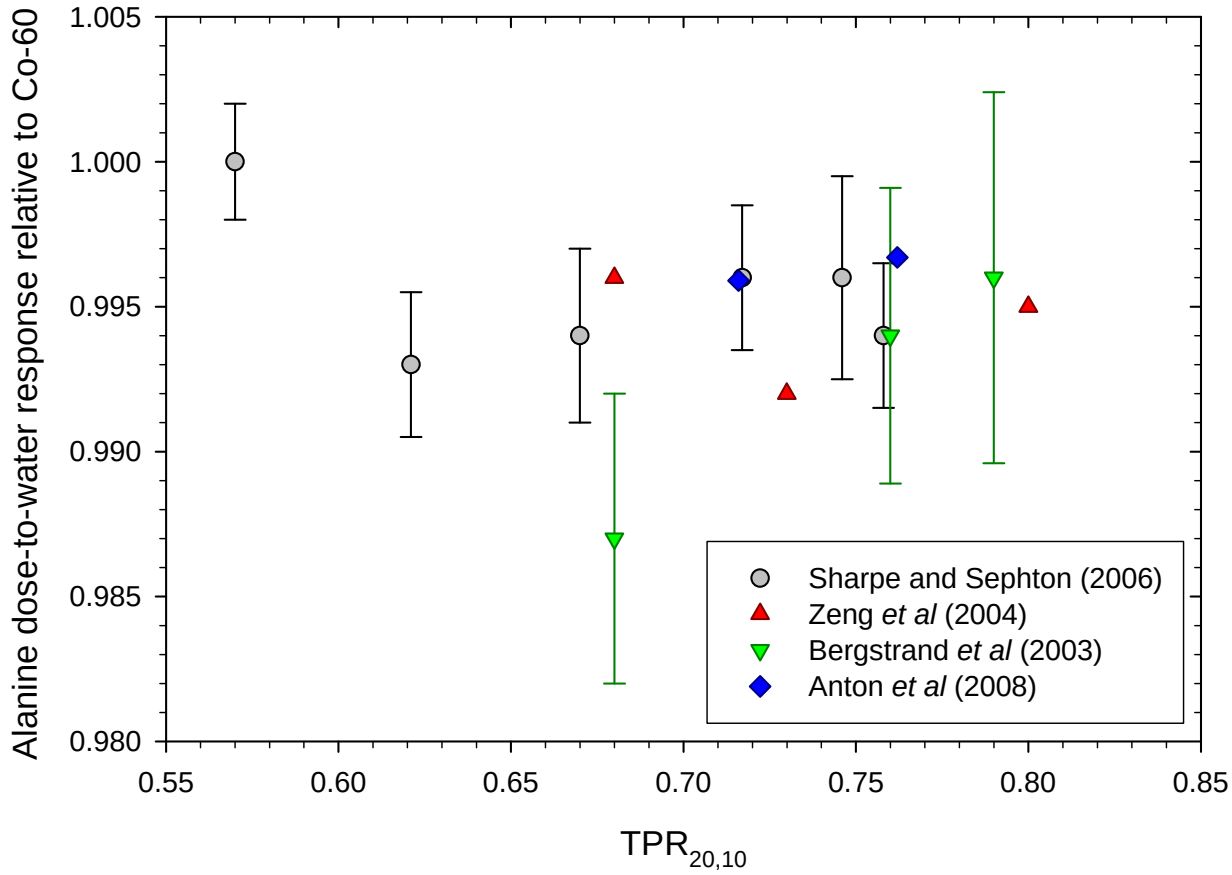
Linearity


Cobalt
6 MV
EPR intensity per unit mass
dose to water (Gy)
relative residual (%)
dose to water (Gy)

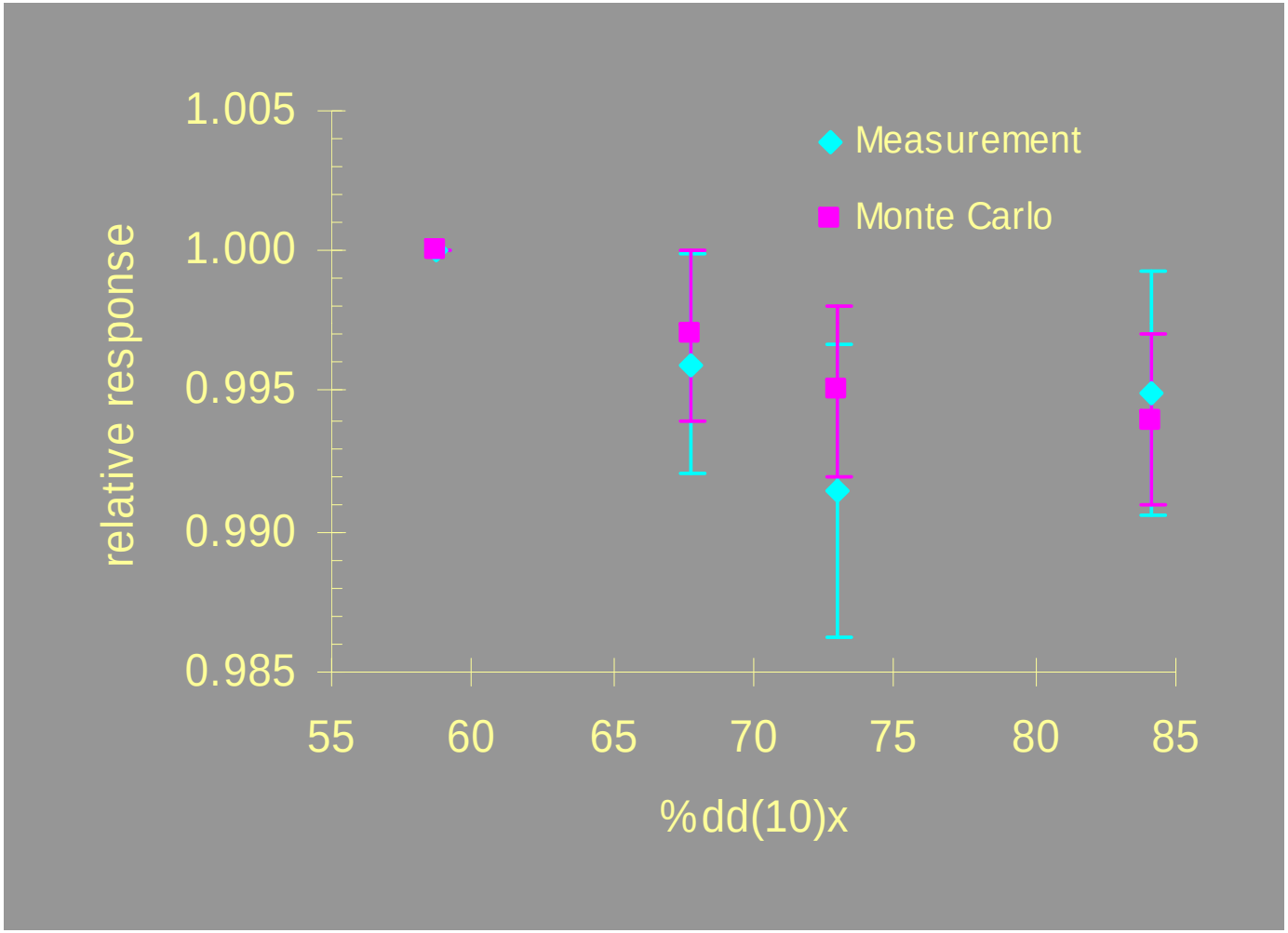
Relative absorbed dose sensitivity



MV photon beams



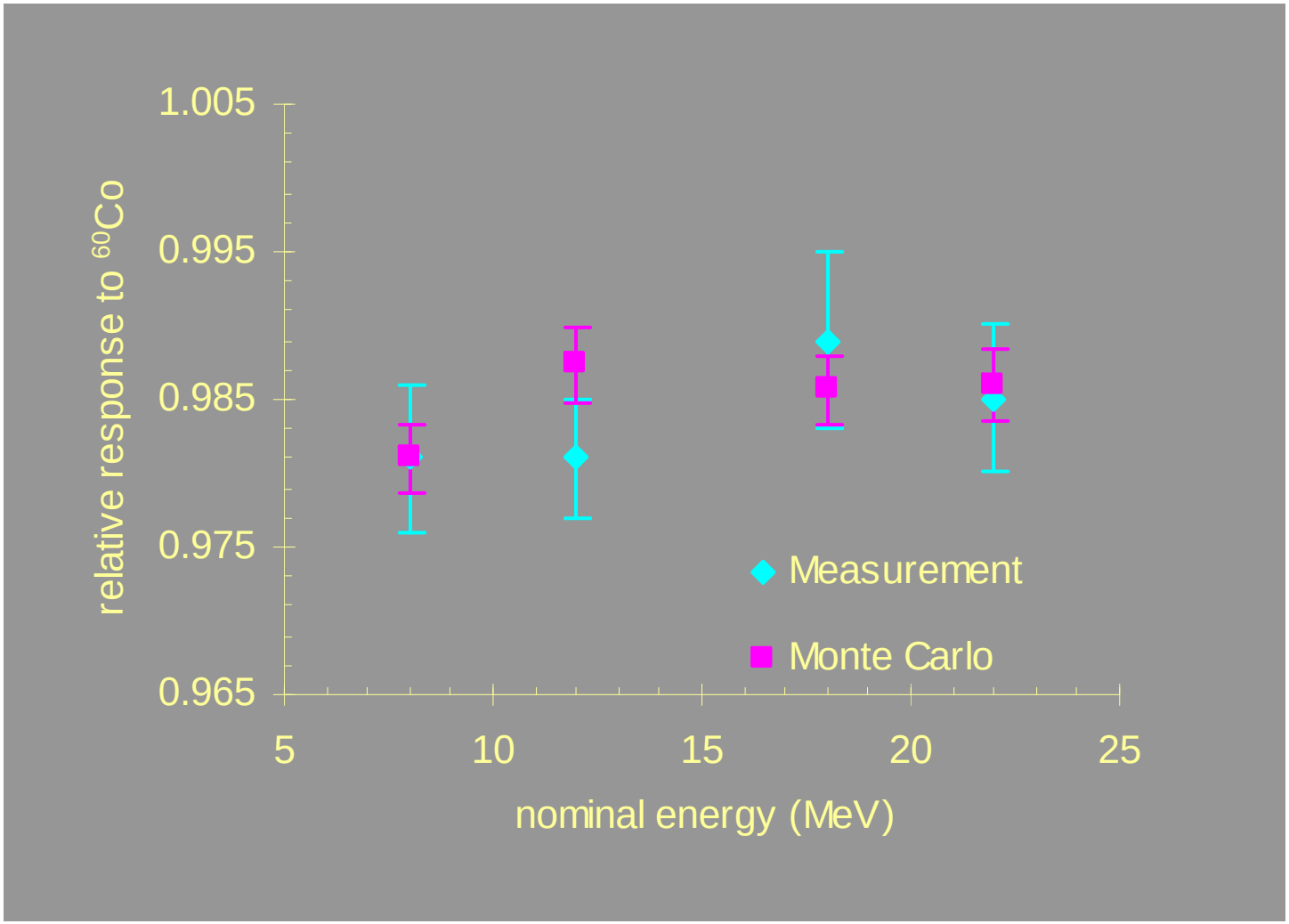
MV photon beams



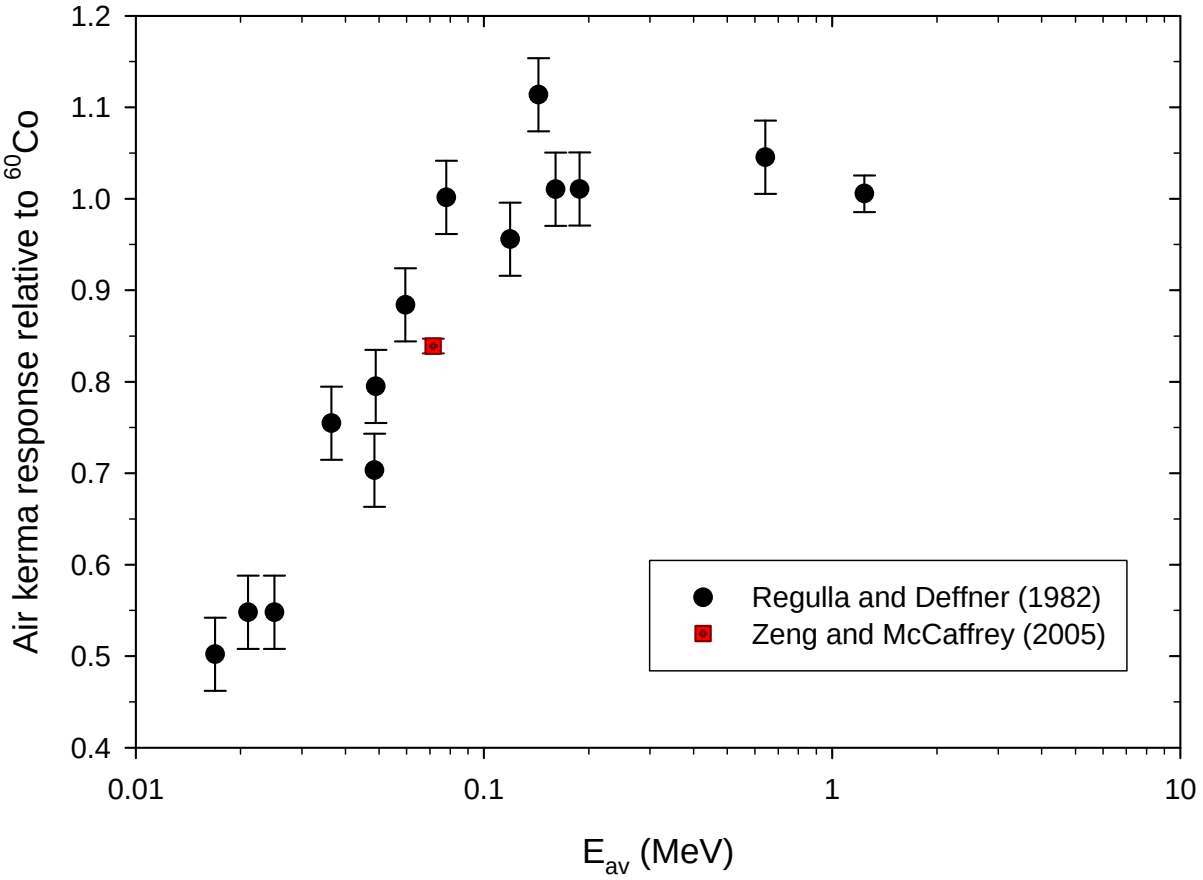
Electron beams

	Relative absorbed-dose response (electrons/^{60}Co)	Standard uncertainty
Bergstrand *et al* (2004)	0.971	0.015
Zeng *et al* (2005)	0.987	0.011
McEwen *et al* (2006)	0.986	0.012

Electron beams



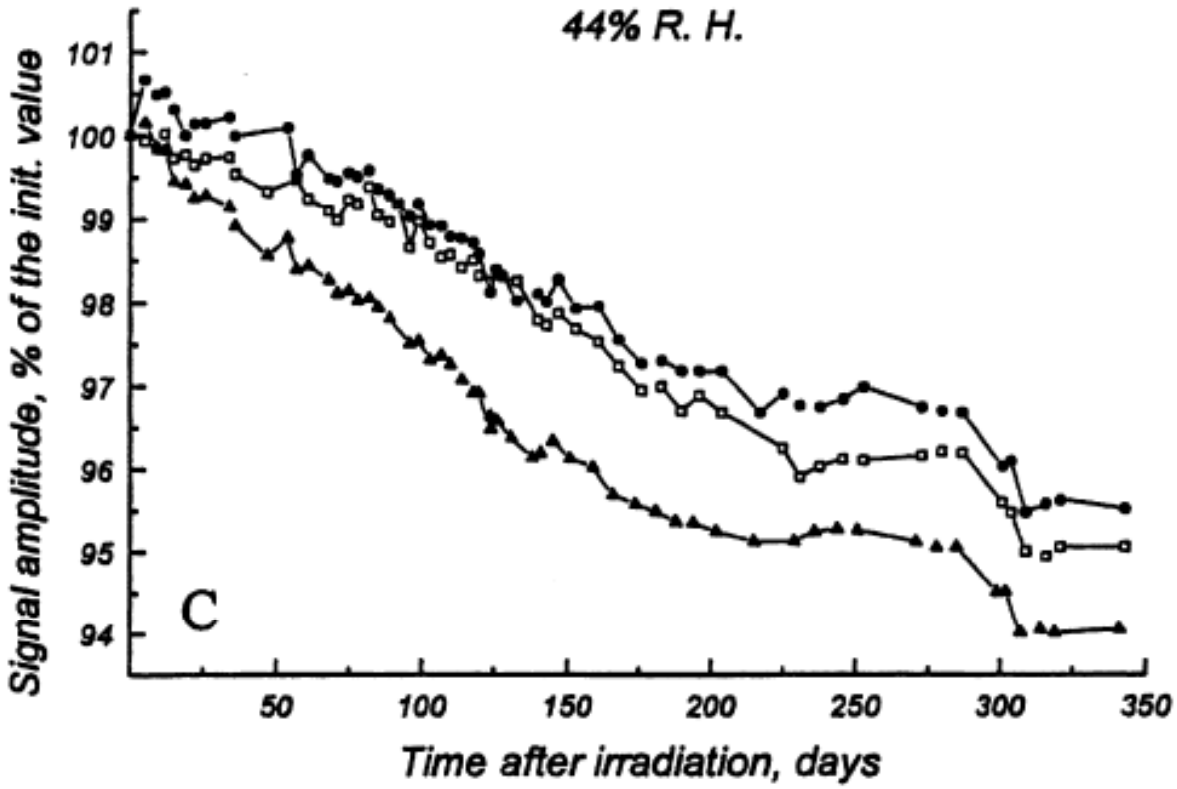
kilovoltage



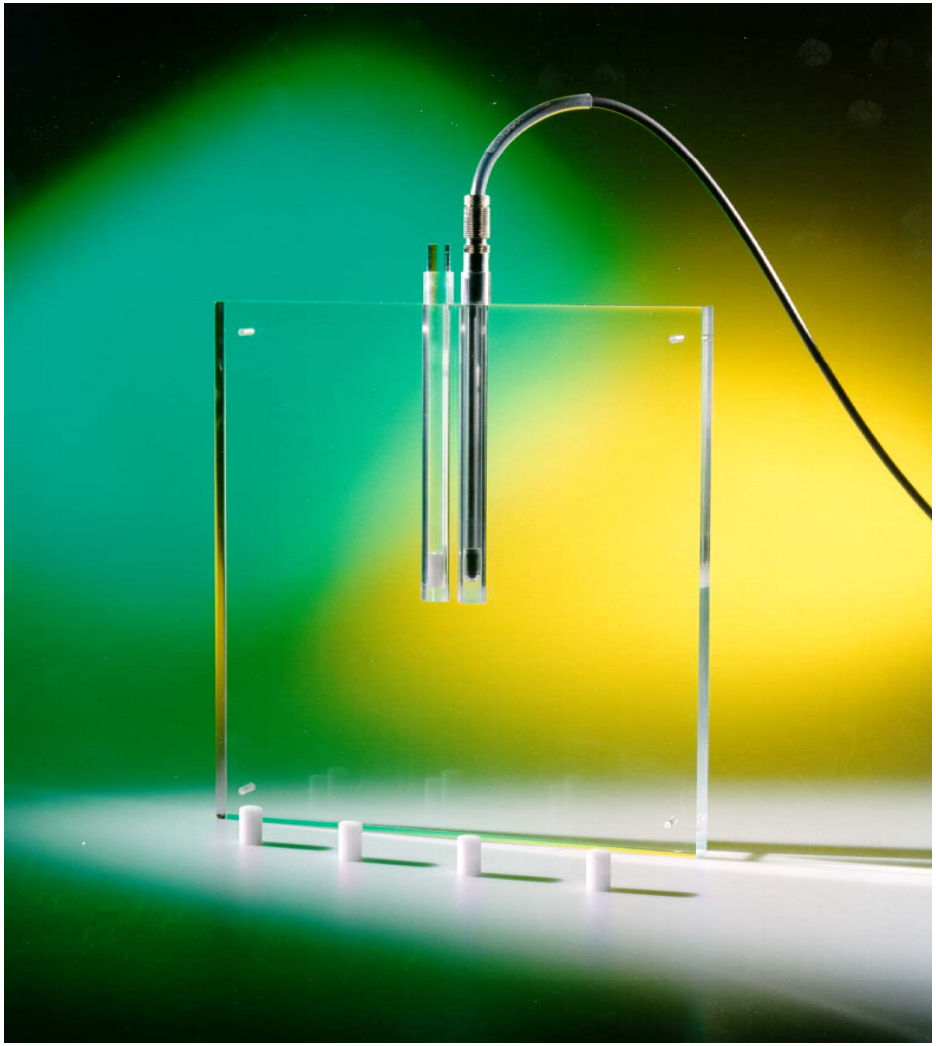
Applications - uncertainties

Component	Standard Uncertainty (10 Gy)
1. Calibration in ^{60}Co	
^{60}Co primary standard realization of dose	0.2 % - 0.4 %
Irradiation temperature	0.05%
Average mass of 4-6 pellets	0.05%
Precision, set of 4-6 alanine pellets	0.1 % - 0.2 %
Overall (Calibration)	**0.2 % - 0.5 %**
2. Measure dose in megavoltage beam	
Calibration reference	0.2 % - 0.5 %
Irradiation temperature	0.1%
Average mass of 4-6 pellets	0.05%
Precision, set of 4-6 alanine pellets	0.2 % - 0.3 %
Inter-pellet variations	0.3 % - 0.5 %
Correction for energy dependence (MV photons)	0.2%
Overall (Measurement of dose)	**0.5 % - 0.8 %**

Applications (I) - audit

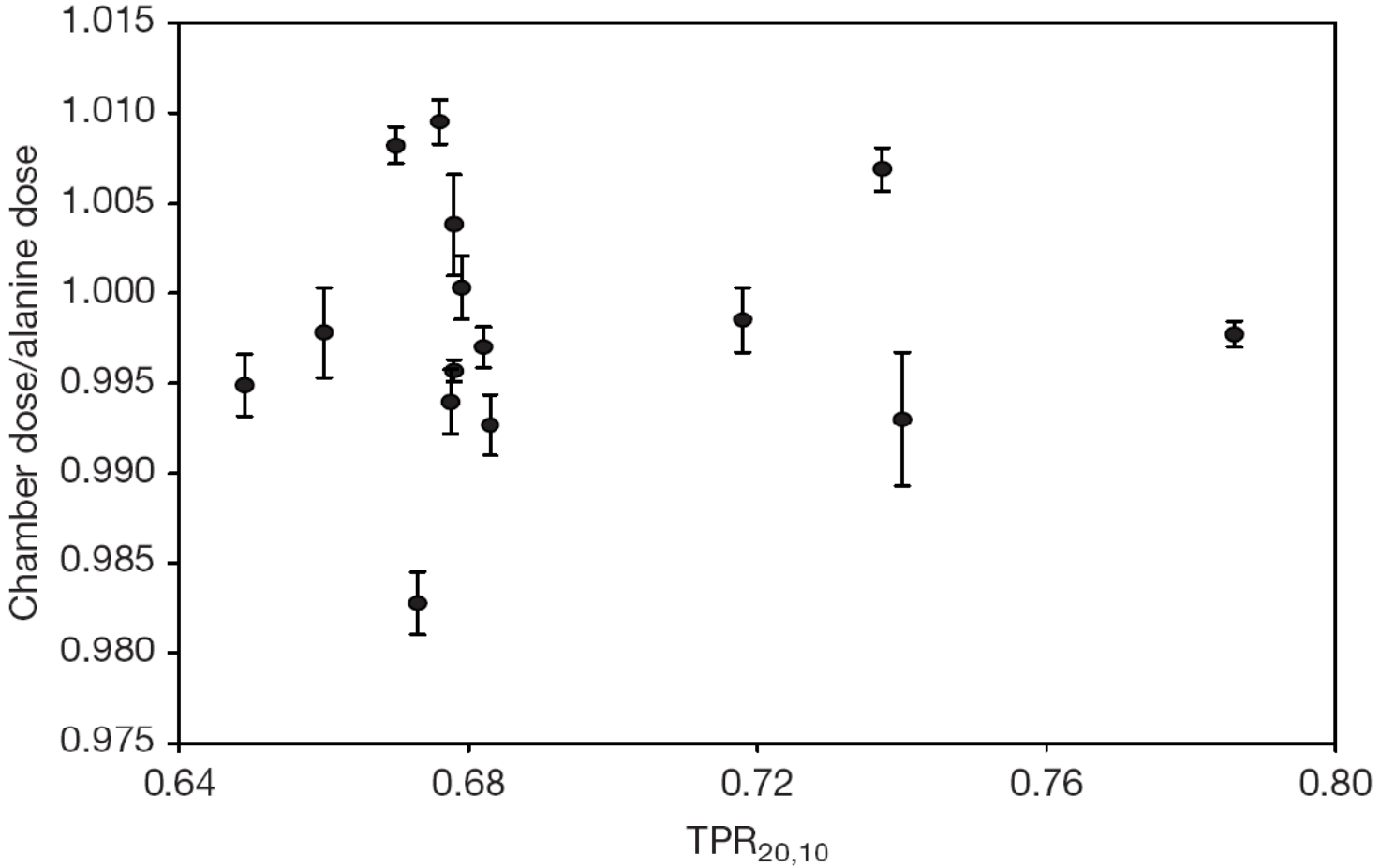


Applications (I) - audit

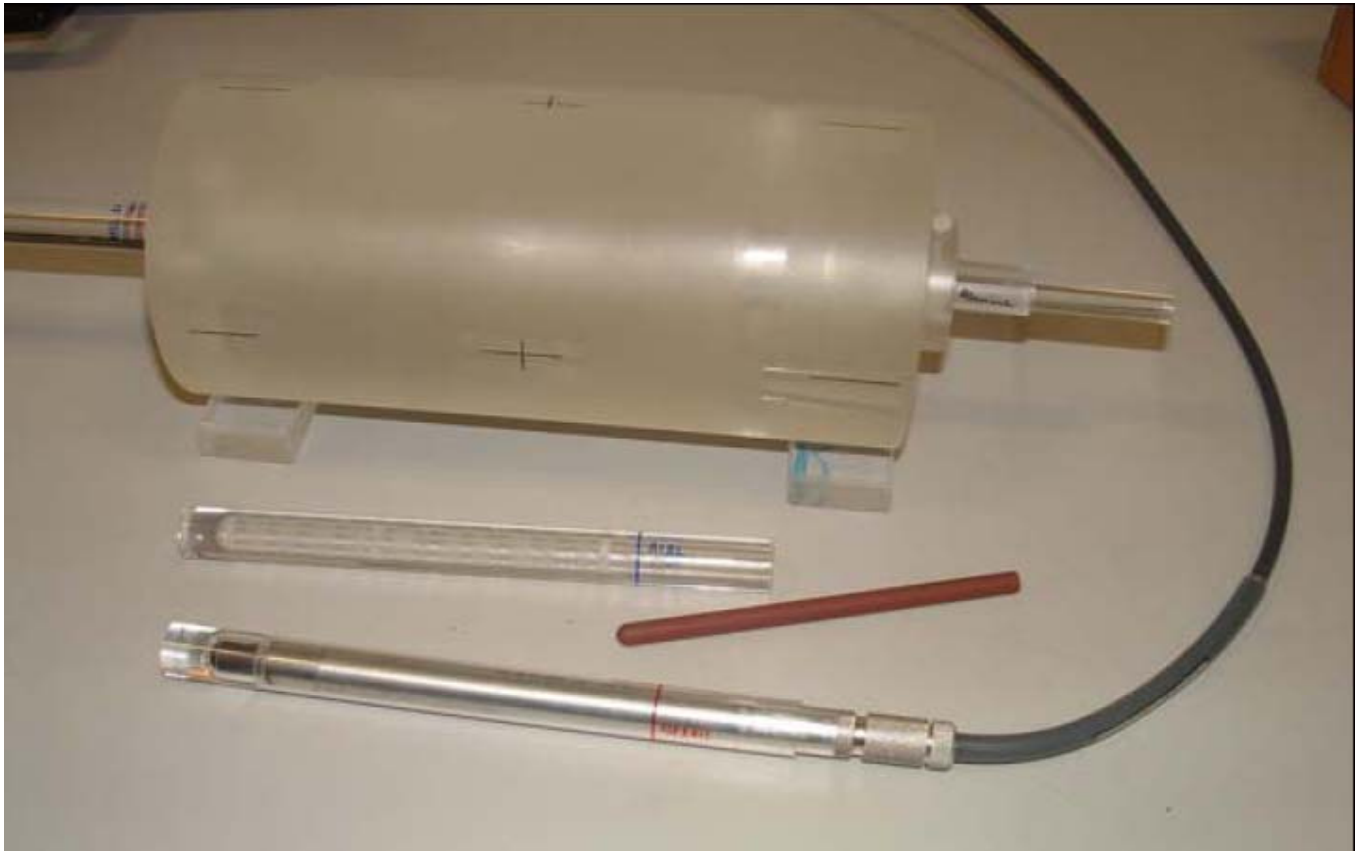


- Dosimeters and phantom can be mailed
- Useful as part off commissioning process
- Also used in UK dose audits

Audit - results



Applications (II) – Tomotherapy



Protocol

Hospital makes CT scans of NPL tomo phantom

Hospital prepares four helical treatment plans, all with cylindrical target volume, 8 cm diameter x 10 cm long, centred on phantom

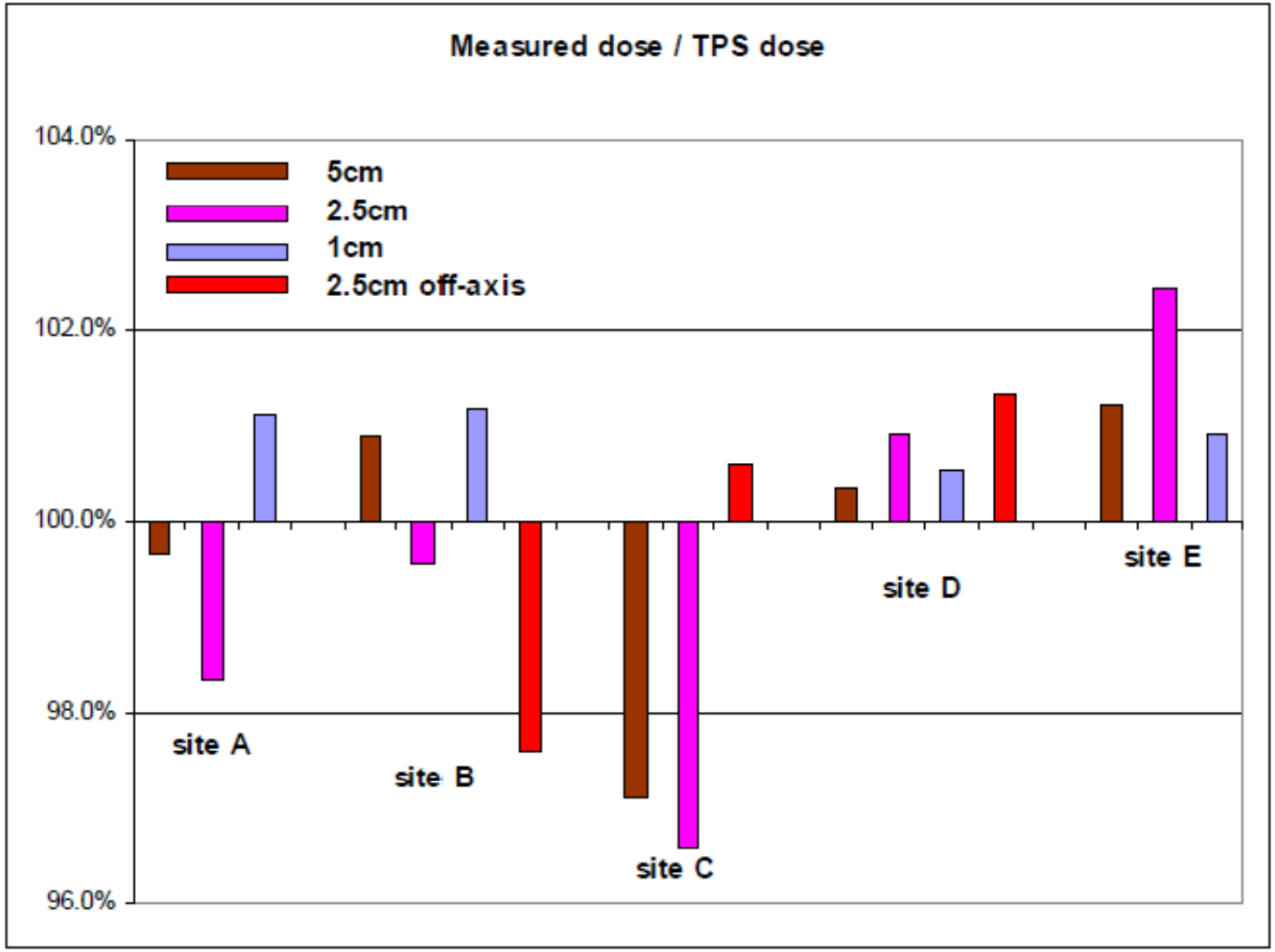
- Phantom concentric with machine
  - 5cm, 2.5cm, 1.1cm thick beam (3 plans)
- Phantom offset horizontally from isocentre by 13 cm
  - 2.5cm thick beam (1 plan)

All plans have helical pitch 0.3, rotation time varies with beam thickness

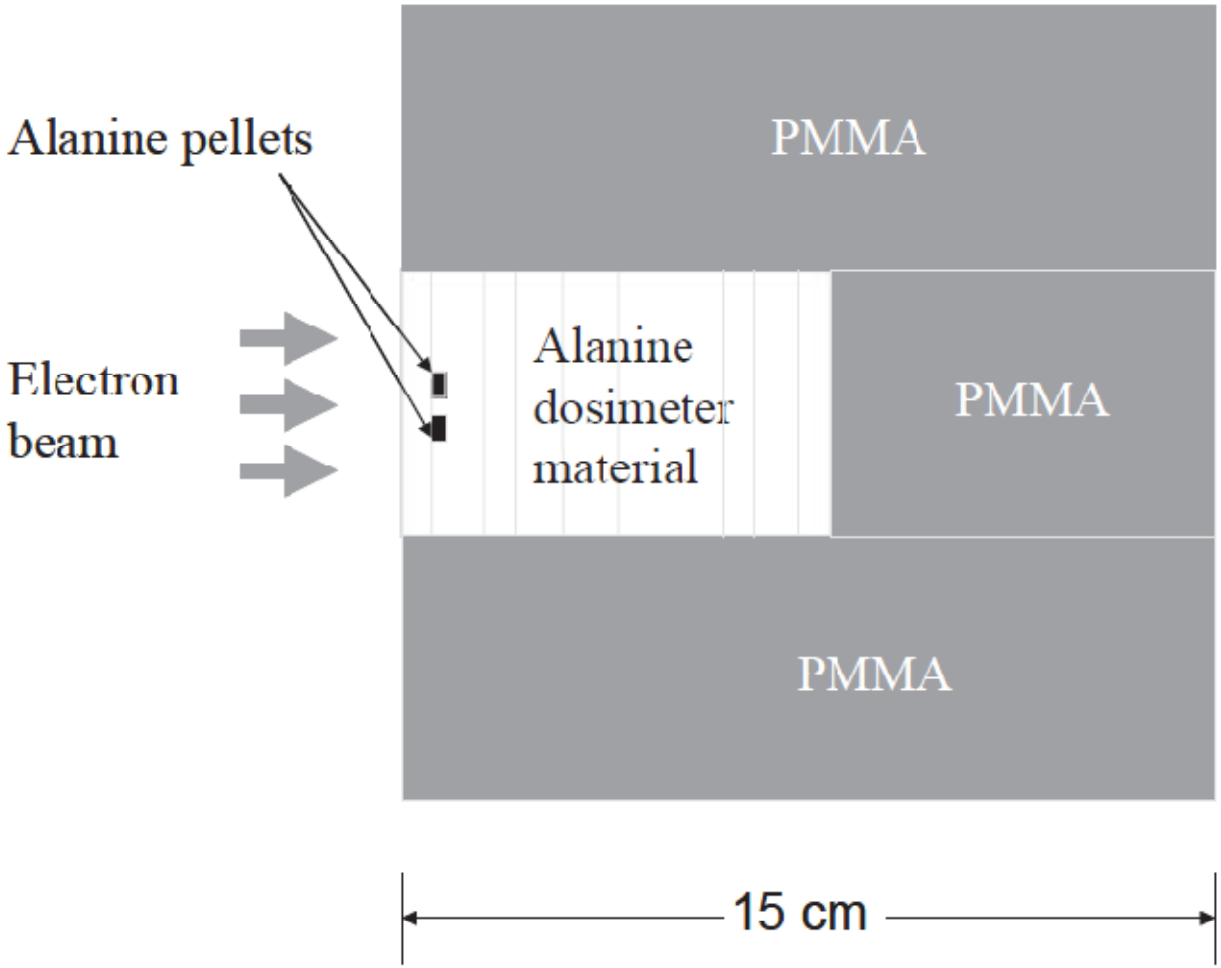
Irradiations performed in 3Gy fractions

- Two sets of 14 alanine pellets per plan, 9Gy per set
- Hospital's secondary standard chamber in each plan (one fraction per reading)

Results


Measured dose / TPS dose
104.0%
102.0%
100.0%
98.0%
96.0%
5cm
2.5cm
1cm
2.5cm off-axis
site A
site B
site C
site D
site E

Applications (III) – electron depth dose



Summary

- Alanine and Fricke are unlikely to feature much in clinical dosimetry
- However, they are well-established systems and have unique properties applicable to special situations
- Keep them in mind, they could be useful one day!

Acknowledgements

Gerhard Stucki – METAS

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Simon Duane, Peter Sharpe – NPL